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■ 論 文 ■

Long-term Radiation Dose Reduction Plan of KHNP

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Abstract - Annual radiation dose limit to radiation worker was substantially lowered in Korea by the adoption of 1990 recommendations of the International Commission on Radiation Protection (ICRP 60) in its legislation. On the other hand, radiation management environment in nuclear power plants is getting more worse because of the accumulation of radiation sources inside the system and the frequent need for maintenance according as the operation years of nuclear power plants increase.

Therefore, Korea Hydro & Nuclear power Co., Ltd. (KHNP) has established a long-term 10 years plan from 2001 to 2010 for the reduction of radiation dose to workers. The plan is aimed for the reduction of annual dose per unit averaged over 5 years from 0.9 man-Sv in 2001 to 0.75 man-Sv in 2010 by radiation source reduction, equipment/tool improvement or new equipment development for easy maintenance, and the improvement of administration and system.

Key words: dose reduction, long-term plan, collective dose

INTRODUCTION

KHNP, a power generation company owned by Korea Electric Power Corporation (KEPCO), was inaugurated on April 2, 2001 and supplying more than 40% of electricity in Korea. As of the end of June 2002, its nuclear capacity and hydraulic capacity are 15,116 MW from 17 units and 535 MW from 27 units, respectively. The share of nuclear power amounts to 94% of its total capacity.

Long-term radiation dose reduction plan from 2001 to 2010 for the reduction of annual dose per unit averaged for 5 years from 0.9 man-Sv in 2001 to 0.75 man-Sv in 2010 was established based on the following three backgrounds.

First, a new radiation dose reduction program was required by KHNP according as the first long-term radiation dose reduction plan launched in 1991 was terminated in 2000. In 1991, annual average radiation dose per unit reached 2.1 man-Sv from 9 units, so the reduction of radiation dose was strongly demanded. Moreover, the reduction of occupational and public dose limits has been anticipated in Korea since ICRP published its new recommendations on radiation protection in 1990. KHNP has achieved a great success by reducing the annual radiation dose per unit to 1.12 man-Sv through the implementation of the first radiation dose reduction program.

Second, legal dose limit to radiation worker will be greatly reduced from 2003 in Korea. Korean atomic law has been already revised in 1998 to cover the ICRP 1990 recommendations. And the revised limit will be applied from 2003. Then the dose limit will be reduced from 50 mSv/yr to 100 mSv for consecutive 5 years (See Table 1).

Third, radiation dose rate from primary coolant system increases because of the accumulation of radioactive corrosion products in the system as the operation years of nuclear power plants increase. On the other hand, more manpower and time are required for maintenance because of the aging of

Table 1. Change in Occupational and Public Dose Limits in Korea from 2003

	Old	New
Occupational	50 mSv/yr	20 mSv/yr average over defined periods of 5 years
Public	5 mSv/yr	1 mSv/yr

Table 2. Trend of Annual Radiation Dose per Unit.

(man-Sv/unityr)

	'92	'93	'94	'95	'96	'97	'98	'99	2000
Existing 9 Units	1.28	1.27	1.21	1.42	1.23	1.01	1.42	1.11	0.95
New Units	-	-	-	0.07	0.34	0.32	0.34	0.46	0.40
Total	1.28	1.27	1.21	1.29	1.06	0.84	1.04	0.85	0.71
World Average	1.68	1.57	1.31	1.35	1.19	1.06	0.99	0.99	0.90

Note) 1. "Existing 9 units" mean nuclear power plants operating in 1991 when the first radiation dose reduction plan was initiated.
2. "New units" mean nuclear power plants engaged after 1992.

Table 3. Trend of Radiation Dose and Tritium Concentration in Wolsong Unit 1

Year	'86 ~ '90	'91 ~ '95	'96 ~ '00
Average Dose (man-Sv/unityr)	1.19	1.52	1.81
Tritium Concentration in Moderator/Coolant (Ci/kg)	23.4 / 0.75	37.1 / 1.48	44.6 / 1.69

system and equipment. Consequently, they result in the increase of radiation dose to workers.

In order to establish the new radiation dose reduction program, root causes for the increase in radiation dose and radiation exposure trend were analyzed based on the annual average radiation dose per unit for recent 5 years, individual radiation doses, and main radiation works. Finally, countermeasure for each cause was reviewed.

2. Radiation Exposure Status

2-1 Radiation Exposure Trend

2-1-1 Annual Average Dose per Unit (man-Sv/unityr)

On the whole, as shown in the Table 2, the annual dose per unit shows a decreasing trend. For the existing 9 units in 1991, the annual average dose was reduced from 1.28 man-Sv in 1992 to 0.95 man-Sv in 2000. However, there still exists possibility of more reduction in the annual dose if considering the reduction of world-average annual dose from 1.68 man-Sv to 0.90 man-Sv for the same period. Even though newly engaged plants maintains low radiation dose level compared to the world average, it is anticipated to show an increasing pattern shortly as the increase of operation years. Therefore, more concentrated efforts should be exerted to lower the radiation dose.

On the contrary, Wolsong unit 1, a PHWR, showed an increasing trend in the annual radiation dose (See Table 3). The increased dose was mainly caused by internal dose increase due to the increase

Table 4. Individual Exposure Trend

Year	'96	'97	'98	'99	'00	'01
Number of Worker Exposed 20 mSv in a Year (Person)	12	7	10	0	0	0
Individual Average Dose (mSv)	1.84	1.23	1.57	1.51	1.41	1.29

○ Radiation Dose during the Planned Overhaul Period : 83% of Total Dose

Total Dose	Overhaul Period Dose	Operating Period Dose
47.4 man-Sv	39.2 man-Sv(83%)	8.2 man-Sv(17%)

○ Radiation dose from S/G Maintenance Works and Refueling Work : 36% of Total Dose

Total Dose	S/G, Refueling Work
47.4 man-Sv	17.0 man-Sv(36%)

in the tritium concentration in the moderator and coolant. Radiation exposure of 0.2~0.4 man-Sv from Gater Spring in Pressure Tube Re-positioning Job started in 1995 during planned overhaul period also seemed to contribute the increasing trend. This job will be continued until 2003.

2-1-2 Individual Dose

Individual average dose increased for the first five years after nuclear era in Korea, reached its maximum of 6.23 mSv/yr in 1981, then was decreasing continuously to 1.29 mSv/year in 2001. The number of workers received radiation dose exceeding 20 mSv in a year increased by the end of nineteen eighties, reached maximum 246 in 1988, then it was decreased. No worker received more than 20 mSv in a year after 1999 (See Table 4).

2-1-3 Main Radiation Work

Analysis of main radiation works done in PWRs from 1996 to 2000 revealed that 83%(39.2 man-Sv) of total exposure (47.4 man-Sv) for 5 years was received from radiation works during the planned overhaul period. Among the works, radiation works for steam generator maintenance and refueling caused 36%(17.0 man-Sv) of total dose.

2-2 Cause Analysis and Countermeasure

Two important root causes for the increase in the radiation dose as the increase of reactor years are maintenance job increase due to the aging of equipment, and radiation dose rate increase due to the accumulation of radiation sources in the system.

2-2-1 Maintenance Work Increase

Table 5 shows the types of maintenance works caused by the aging of equipment and the radiation dose received during those works from 1996 to 2000. Radiation dose from those works was about 5.8 man-Sv which was equivalent to 12% of total dose (47.4 man-Sv) received during the same period. It implies that the reduction of radiation work number and work-hour through the improvement of equipment in old plants can be important measures for the reduction of radiation dose.

2-2-2 Radiation Dose Rate Increase

In order to see the effect of radiation source (corrosion product) accumulation on the dose rate, dose rate trend inside S/G chamber was investigated from the beginning of plant operation.

Table 5. Radiation Works Due to Aging of Equipment

Year	Total Collective Dose(man-Sv)	Radiation Works Due to Aging of Equipment	
		Type	Exposure (man-Sv)
1996	8.72	YG #1 Safety Injection V/V Maintenance KR #4 RCP TVCS/DACS Replacement	0.31 0.67
1997	8.80	KR #3 Safety Injection V/V Maintenance	0.31
1998	11.48	KR #1 S/G Replacement KR #1,3 RTD Bypass Line Removal KR #2 RCP, RHR Pump Maintenance YG #1 S/G Tube Plugging, Deplugging, Safety Injection Line Replacement YG #2 S/G Cleaning, Inspection S/G Tube Enlargement	1.53 0.77 0.43 0.12 0.10 0.40 0.09
1999	9.27	KR #1 RCP TVCS/DACS Replacement KR #2,4 RTD Bypass Line Removal UJ #1 S/G Tube Plugging, Sleeving	0.23 0.47 0.14
2000	9.18	YG #1 RTD Bypass Line Removal YJ #1,2 In-core Instrumentation Replacement	0.36 0.17
Total	47.45		5.79

Note) YG, KR, and UJ mean Younggwang, Kori, and Uljin, respectively.

Table 6. Comparison of Dose Rate Inside S/G Chamber and Radiation Dose from S/G Maintenance Works before and after S/G Replacement in Kori #1

	S/G Chamber Dose Rate (mR/hr)		Radiation Dose from S/G Maintenance Works (man-rem)
	Maximum	Minimum	
1997년	10,750	7,120	46.1
1998년	S/G Replacement		
1999년	3,700	2,900	13.0
Decreased Ratio	66%	60%	72%

Generally, the dose rate after 10 cycle was 1.8 times higher than the dose rate at the beginning of operation. Table 6 shows the comparison of radiation doses from S/G maintenance works before and after S/G replacement in Kori unit 1. In this table, the close relationship between the change in the dose rate inside S/G chamber and the radiation dose from S/G maintenance works can be confirmed. Namely, radiation dose can be effectively reduced by controlling the production of radiation sources and/or by removing the produced radiation sources.

3. Radiation Dose Reduction

In order to set the radiation dose reduction goal for each unit, anticipated dose reduction from

Table 7. Average Radiation Dose Goal in KHNP (man-Sv/unit-yr)

Year	Recent 5 Years	2001~2003	2004~2006	2007~2010
Cumulative Dose Goal	0.90	0.83	0.78	0.75

Table 8. Cumulative Radiation Dose Goal for Each Plant (man-Sv/2units-yr)

Kori Plant 1	2.88	2.29	2.20	2.13
Kori Plant 2	2.18	1.95	1.45	1.46
Younggwang Plant 1	2.02	1.70	1.64	1.62
Younggwang Plant 2	1.00	0.98	0.95	0.92
Wolsong Plant 1	2.59	2.54	2.47	2.15
Wolsong Plant 2	1.56	1.56	1.56	1.56
Uljin Plant 1	1.38	1.36	1.36	1.36
Uljin Plant 2	0.90	0.90	0.90	0.90

planned activities in each plant was evaluated. Then the cumulative radiation dose goal for each plant was determined as a value subtracted the anticipated dose reduction from the annual radiation dose averaged over recent 5 years. Table 7 shows the average cumulative radiation dose goal in KHNP, and Table 8 shows the cumulative radiation dose goal for each plant (2 units).

4. Radiation Dose Rate Reduction

4-1 Radiation Source Reduction

In order to remove corrosion product produced in the primary coolant during normal operation of the nuclear power plant effectively, reactor shutdown chemistry should be optimized. For this purpose, advanced appropriate instruments will be purchased for the timely chemical treatment by continuously measuring chemical conditions in the coolant. In addition, a working committee among relevant departments will be formed for the pre-planning and post-evaluation of shutdown water chemistry, and the share of knowledge and experience through information exchange among plants. More aggressively, chemical decontamination of the primary coolant system is being also considered.

For the suppression of radiation source production, cobalt amounts contained in the materials used in the primary coolant system should be minimized. In the nuclear power plants under construction, the cobalt amounts in S/G tube and coolant pipe cladding materials are gradually decreasing as shown in Table 9. However, Stellite, a cobalt based alloy, is still used in some reactor internals and the hardfacing surface of valve. KHNP will launch a research project in 2002 to establish the method of substituting cobalt free alloy for the Stellite.

In addition, the installation of tritium removal facility was initiated in 2000 to reduce internal exposure in PHWR by extracting tritium contained in the moderator and coolant. This facility will have been completed in 2005.

4-2 Improvement of Equipment and Installation

Equipment or installation required a lot of man power and time for maintenance because of aging or frequent trouble will be replaced, improved, or modified. Equipment causing unnecessary exposure

Table 9. Use of Low Cobalt or Cobalt Free Material in Korea

Component		Before Ulchin #3,4	Yonggwang #5,6	Ulchin #5,6	APR 1400
S/G Tube		0.1 w/o	0.015 w/o	0.015 w/o	0.014 w/o
Clad	Stainless Steel	0.2 w/o	0.2 w/o	0.2 w/o	0.05 w/o
	Ni alloy	0.2 w/o	0.2 w/o	0.1 w/o	0.05 w/o
Hardfacing/ Reactor Internal		No Application			Not Decided

because of complicated work procedure will be also improved or replaced regardless of its performance. In order to reduce radiation exposure fundamentally by minimizing maintenance need and maintenance time, manual or semi-automatic equipment for inspection and maintenance will be replaced with automatic advanced type. The following improvements are planned in the present program.

4-2-1 Improvement of Reactor Coolant Temperature Measuring System

RTD by-pass line, in which reactor coolant temperature thermocouple is installed, caused frequent trouble. Consequently, high radiation exposure was inevitable from its maintenance work. Therefore, new thermometer is being installed directly in the main coolant pipe after removing the RTD by-pass line. Until 2001, the improvement job has been completed in Kori units 1-4, and Younggwang units 1 and 2. By improving the system, 50 mam-mSv per unit was saved annually.

4-2-2 Installation of Permanent Seal Ring in the Reactor Cavity

By installing a permanent seal ring between reactor vessel and concrete structure, repetitive sealing job for every refueling can be avoided. Such a simplified refueling job procedure can contribute to the reduction of radiation exposure to workers. The installation job will be finished until 2007 in Kori units 1-4, and Younggwang units 1 and 2. The cumulative dose reduction from 6 units is anticipated to be 35 man-mSv annually.

4-2-3 Introduction of Integrated Reactor Head Assembly

Working hour for assembling and disassembling will be greatly shortened by improving the complicated reactor head installations as an integrated assembly for easy assembling and disassembling. The job will be finished until 2009 in Kori units 1-4, and Younggwang units 1-4. The cumulative dose reduction from 8 units is anticipated to be 120 man-mSv annually.

4-2-4 Improvement of Reactor Coolant Pump Shaft

RCP maintenance work can be done without disassembling reactor pump coolant shaft by improving the existing one-piece shaft from pump motor to rotor as a spool piece type. The job will be initiated in 2004 for Kori unit 1. Radiation dose reduction of 10 man-mSv is expected annually.

4-2-5 Introduction of Advanced S/G Nozzle Dam

Working hour reduction can be achieved through the replacement of an existing bolt-tightening type nozzle dam with an air-expansion type nozzle dam. This advanced nozzle dam has been already introduced in Kori unit 2 and Younggwang unit 2 in 2001.

4-3 Improvement of Administration and System

4-3-1 Improvement of Internal Dose Evaluation System

Internal dose evaluation program and internal exposure management procedure will be modified in order to reflect the ICRP 60 recommendations.

4-3-2 Improvement of ALARA Review System at the Design and Construction Stages

Dose reduction program at the operation stage of nuclear power plant requires a lot of cost while its effect and application range is limited. Therefore, persons with enough experience from the operation should participate in the ALARA review from design and construction stages for the effective implementation of ALARA. Administrative system will be improved to enable operation staff to participate in the design ALARA.

4-3-3 Enactment of Radiation Safety Award

By awarding a prize to individuals and groups contributing to radiation safety, it is possible to inspire concerns of radiation safety into workers heart. Ultimately, it will lead to radiation dose reduction.